THE INFLUENCE OF WEATHER ON STREET-CAR TRAFFIC IN DULUTH, MINNESOTA

By EUGENE VAN CLEEF

If street-railway companies could estimate their daily traffic twenty-four to thirty-six hours in advance they could effect a great saving of money for themselves and could give the public improved service. However, a forecast seems impossible when one considers the many different factors likely to influence the traveling public. An analysis of the possible influences shows the weather to be the largest single factor. Yet just how effective it is and the manner in which its changes are reflected in passenger traffic have remained unknown. Through the courtesy of the officials of the street-railway company of Duluth, Minnesota, who have made available

Weather Report and Key to Units Representing Weather Conditions

Time	Temperature		Units	Condition of Atmosphere	Key
	Plus	—			
5 a. m.	48	108	148	Clear	Rain or Snow—0 Plus degrees temperature
12 m.	58	30	88	Cloudy	Cloudy Sky – 30 Plus " "
6 p. m.	46	60	106	Partly Cloudy	Part Cloudy Sky—60 Plus " "
12 p. m.	42	0	42	Rain	Clear Sky – 100 Plus " "

........384..........Total Units for 24 hours ending at midnight.

FIG. 1—Facsimile of blank form used by the street-car company of Duluth, Minn., to record "weather units."

The figures in the second column under "Temperature" are intended to express, not temperature, but the "condition of the atmosphere" according to the key given in the last column. The first figure should read 100.

the requisite data and have very kindly co-operated in this work, it has become possible to compare the variations in passenger traffic in that city with fluctuations in daily weather conditions. Duluth was selected for this study for the following reasons: (1) the number of people who walk to and from work in the mornings and evenings, respectively, is quite large; (2) the number who walk home for lunch and then walk or ride back to their place of business is unusually large; (3) the public as a whole is especially given to long walks, or "hikes"; (4) the love for out-door life has hardened many people to all varieties of weather; (5) the writer is well acquainted with the community and its peculiarities.

On inquiring at the offices of the street-car company as to its interest in the significance of weather influences upon its traffic, it was learned that it had become concerned in this vital matter many years ago. For twenty years it had kept such a record. Observations for temperature, precipitation, and cloudiness are made by the car-starter located approximately in the center of the city and entered on what are termed "weather unit" blanks, a sample of which is shown in Figure 1. The thermometer used has been of mediocre quality and has not always had the proper

exposure. To the temperature is added a number indicating the condition of the atmosphere in an arbitrary scale ranging from 0 when precipitation occurs to 100 for a clear sky. The total number of units indicates the relative quality of the day: if they are high the day is a good one; if low it is not so good. No absolute standard of reference has been calculated. The figures are compared with a sort of sensible average, dependent upon the season of the year. For example, 384 units, as given in Figure 1, represent a poor April day, whereas 450 units would represent a very fair day for that season. In so far as the scheme takes into account three of the most common elements, temperature, precipitation, and cloudiness, it possesses merit; it lacks, however, the fourth very common factor, the

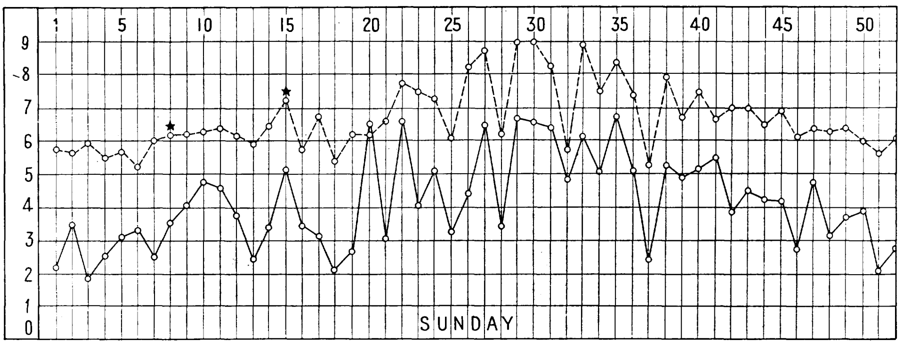

FIG. 2—Diagram showing the relation of street-car traffic to weather in Duluth, Minn., on Sundays during 1914.

The dotted curve represents passengers per mile per day. The continuous curve represents "weather units" as calculated by the street-railway company. The numerals at the top of the vertical lines indicate the number of the week in the year. The figures at the left of the horizontal lines represent the passengers per mile in units and at the same time the "weather units" in hundreds. The stars refer to holidays or other special occasions.

wind. These records are now kept only as tradition. At one time they were observed rather closely in the hope that they might reveal information which would aid the company to run its system more efficiently both for the public and for itself.

To afford a proper basis for this investigation the total number of passengers carried was reduced to terms of the number of passengers carried per mile per day and plotted with the weather units. These data were plotted with reference to the respective days of the week, i. e. all the Sundays of the year were grouped in one curve, the Mondays in another, and so on. It is obvious that to compare a Sunday with a Monday would be illogical, the former a day when most of the business world rests, in contrast with the latter, a day of great activity. It would be just as bad to compare any other two days of the week, since the business world inclines toward the performance of different kinds of business on different days. Figure 2 illustrates the curves for Sunday only. The parallelism of these

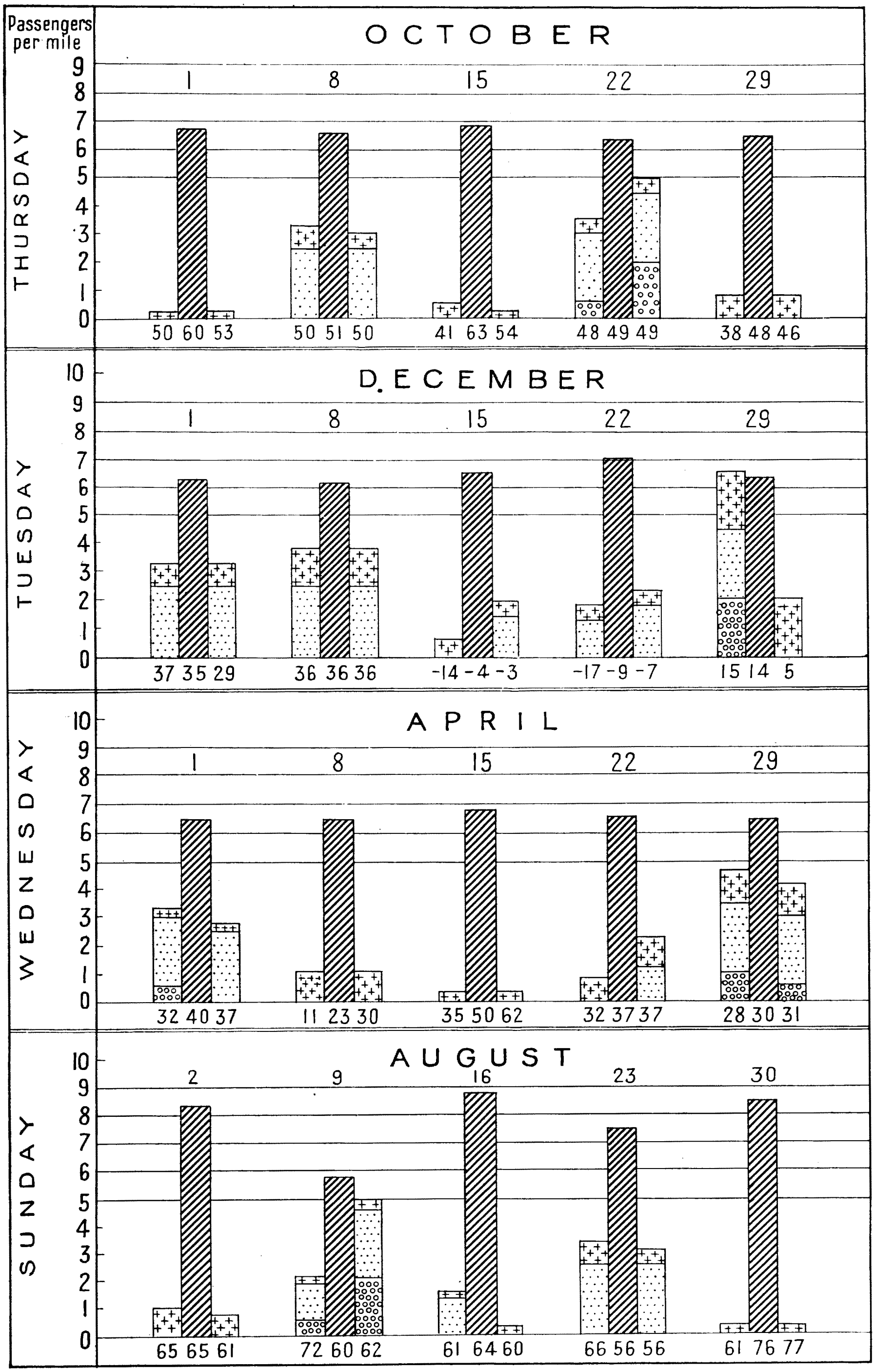

FIG. 3—Diagram showing the relation between the specific weather elements and the street-car traffic in Duluth, Minn., on selected days at different seasons in 1914. (For explanation, see bottom of p. 129.)

curves is striking. (It is similar for the other days of the week, though not quite so emphatic.) Even where the variation in the passenger curve is slight, as at the left of the diagram, its meaning is none the less important. The variation oftentimes represents only one-tenth of a passenger per mile per day. When the average number of miles run per day amounts to 9,539, as it does for Tuesdays, for example, a difference of one-tenth of a passenger per mile means 953.9 passengers per day, and the fare which they pay equals $47.69. This decrease in traffic may be the equivalent of an actual loss to the company. Such a loss occurring on very many days may mount into the thousands of dollars and soon prove serious. Hence the tenths earn a right to as much respect as the whole numbers. Clearly, then, so far as revealed by the curves in Figure 2, weather and traffic are closely related. In very few instances does the parallelism break down. But nothing in these curves indicates what elements exert the greatest influence or whether perhaps all are of equal significance. Hence the problem really begins here.

The year 1914 was selected in this initial effort to solve the problem because it approaches very nearly the ideal. The weather was not unusual; no strikes occurred, and "jitneys" had not yet made their appearance. It seemed at first as though many years of data would be necessary for conclusive evidence; but the results thus far have proved so substantial that one normal year has been accepted as affording a satisfactory basis for work for the present.

How to plot the data for ready comparison presented a small problem in itself. Temperature, precipitation, wind velocity, and cloudiness were the elements chosen as those which probably exert the maximum influence. Humidity would hardly be effective in a region like that of Duluth, where days of great heat combined with high humidity are rare. The combination of high humidity and cold winds, producing "raw" weather, is also uncommon. Sunshine is the complement of cloudiness and therefore appears automatically in the figures for cloudiness. Special phenomena such as thunderstorms, blizzards, and severe rainstorms are not incorporated in the graphs but are accounted for in the detailed weather record from which the figures for the graphs were taken.

The day was divided into morning (A. M.) and afternoon (P. M.), and the average condition for these respective periods was recorded. In the case of temperature the figures were taken at three periods—7 A. M., 12 noon, and 6 P. M., the hours when the traffic is heaviest. In Figure 3

EXPLANATION OF FIG. 3—The heavily shaded central column in each group represents the number of passengers carried per mile according to the scale on the left, on the day indicated by the date above. The outer columns in each group represent, according to their symbols: precipitation (small circles), cloudiness (dots), and wind velocity (crosses), the left-hand column indicating prevailing conditions between 7 A.M. and 12 M, and the right-hand column those between 12 M. and 6 P. M.

The unit of scale for these elements is one-fourth the passenger mile unit on the left of the diagram. One such unit represents one unit in a scale of ten for cloudiness and wind velocity; for precipitation the scale is: trace, 2 units; light, 4; heavy, 8.

The three figures below each group of columns represent the temperature at 7 A. M., 12 M., and 6 P. M., respectively, reading from left to right.

extracts from the original charts are given, to illustrate the scheme for plotting the data. This method brings six items at once before the eye of the reader: the date, passengers per mile per day, temperature, precipitation, winds, and cloudiness. In the original charts the months were grouped as follows: December-January-February, March-April-May, June-July-August, and September-October-November, approximating rather closely to the true seasons in this vicinity. Accordingly seasonal phenomena could be easily observed. The second triad of months can hardly be termed spring in this region. A more proper designation is "transition season," which will be used hereafter. Holidays and other special days[1] were eliminated from consideration, although the influence of the weather even on these occasions is readily detected.

The relation of traffic to weather could be better shown if figures were available for the morning traffic as distinct from that of the afternoon. Again, if the data for the non-working travelers were at hand the problem would be very much simplified. The workers who travel regularly each day represent the constant, the others the variable. But since none of the above data have been compiled or are even possible of compilation one must try to recognize in the figures at hand the resolution of the constant and the variable.

The average of the number of passengers carried per mile per day for the respective days of the week was calculated in order to ascertain the daily variation in traffic for the seasons. The results are given in Table I.

Table I—Average Number of Street-Car Passengers Carried in Duluth, Minn., per Mile per Day for Each Day of the Week and for Each of the Four Seasons, 1914

	Dec.-Jan.-Feb.	Mar.-Apr.-May	June-July-Aug.	Sept.-Oct.-Nov.
Sunday	5.9	6.2	8.3	6.7
Monday	6.1	6.5	7.0	6.6
Tuesday	6.2	6.5	7.2	6.5
Wednesday	6.2	6.5	7.2	6.6
Thursday	6.3	6 6	7.1	6.7
Friday	6.1	6.5	6.9	6.5
Saturday	6.9	7.4	7.8	7.4

These averages are employed as representative of the normal passenger traffic. For example, 6.2 is taken as the normal number of passengers

[1]

January 1	New Year's Day
February 22	Washington's Birthday
March 1	Ski tournament
April 12	Easter Sunday
May 30	Decoration Day
June 11	Animal show
June 24	Swedish carnival
July 4	Independence Day
July 23	Circus
August 13	Grocers' and butchers' picnic
September 6	Labor Day
September 11	Industrial exposition
October 31	Halloween
November 26	Thanksgiving Day
December 25	Christmas Day

carried per mile per day on each of the Sundays during the transition season. Table II illustrates how certain comparisons were made. In the

TABLE II—ILLUSTRATION OF THE METHOD USED TO DETERMINE THE FACTORS WHICH INFLUENCE STREET-CAR TRAFFIC IN DULUTH, MINN.

	∓	T	P	W	C	H	P.C.
June 5	—	×	....	×	....	....	6.5
12	—	×	....	....	....	....	6.8
19	—	×	....	×	....	....	6.8
26	—	×	×	×	....	....	6.7
July 3	+	....	×	....	....	×	8.6
10	—	×	....	×	....	....	6.6
17	—	×	....	Calm	....	....	6.8
24	+	×	....	"	....	....	7.2
31	+	×	....	....	....	....	7.3
Aug. 7	+	×	....	....	....	....	7.0
14	+	....	....	×	....	....	7.0
21	+	×	....	....	....	....	7.1
28	—	×	....	×	....	....	6.7
					Average for the season		6.9

Abbreviations—
— Decrease T—Temperature W—Wind H—Holiday
+ Increase P—Precipitation C—Clouds P. C.—Passengers carried per mile

first column opposite the dates is indicated the deviation in the number of passengers from the normal (6.9 for the season) by a minus (—) sign or a plus (+) sign, according to the sense of the deviation. Under the other column headings a cross-mark (×) occurs according as the particular element or elements seemed to be the determining cause of the deviation. Decreases were primarily considered. One must necessarily be more interested in a decrease in passengers, since this means reduced profits. Finally, the crosses in the respective columns were added together. In 118 days when a decrease occurred wind figured 70 times, temperature 56, precipitation 51, and clouds 29. These elements played a part either independently or in combination. From these results it would appear that wind is the most influential factor. During this period there occurred a total decrease in traffic of 33.3 passengers per mile or .28 passenger per mile per day. If the average daily mileage is 9,546.7 (this figure excludes Sundays, for which the mileage averages 9,043.4), then the total reduction in receipts per day amounts to $133.65, or, for 118 days, $15,770.70, surely an amount worth trying to save.

An analytical study of the statistics and charts develops five well-defined conditions which may cause a decrease in traffic. (The references to Figure 3 are meant only to illustrate and not to prove the assertions.)

(1) Precipitation is practically always effective excepting when it occurs in the form of a light snow unaccompanied by wind. Light snow in itself seems to have little influence. In Figure 3 compare October 22 with October 8, days differing essentially only in their precipitation.

(2) Precipitation accompanied by a strong wind is more effective than if accompanied by a weak wind.

(3) Other elements being the same or very similar, a considerable drop in temperature will reduce traffic.

(4) Even when other elements are dissimilar, a decided drop in temperature reduces traffic that would otherwise assume normal proportions or even rise above the normal. In Figure 3 compare April 8 and 22. They differ primarily in temperature.

(5) A moderate to strong wind, usually 4 or above (Beaufort scale), reduces the number of passengers. In Figure 3 compare December 1 and 8. The drop in patronage can be only accounted for on the basis of wind.

Cloudiness has a slight tendency to decrease traffic. The evidence, however, is not fully convincing. Fogs, as one would expect, cause a reduction. Heavy storms, either of snow or sleet, or thunderstorms are reflected in the passenger returns.

The various factors assume the following order (the most effective first) with respect to their capacity for reducing traffic:

(1) Precipitation accompanied by wind;

(2) Precipitation alone, except light snow;

(3) A considerable drop in temperature accompanied by a moderate to strong wind;

(4) A strong wind—most effective when in combination;

(5) A decided drop in temperature regardless of other elements.

A few apparent anomalies occur. In one instance a high wind accompanying low temperature seemed to be the cause of an increase in traffic. On another occasion a heavily drifting snow failed to produce a decrease in patronage; and in three other cases a high wind accompanying a moderately high temperature increased traffic. A possible explanation of the last situation may be that the warmth of the day lured people out of doors who subsequently were driven to the cars by the unpleasantly high wind. Furthermore, the department stores report that, in the event of a three-day storm, their receipts go up on the third day, in spite of unfavorable weather. People become tired of remaining indoors so long and venture forth in spite of the weather. These anomalies are cited to indicate some of the complications that arise when one endeavors to formulate a rigid rule with regard to weather influences.

If the five weather factors given above are correct they should prove up in a traffic forecast. One hundred such forecasts were made covering the period from March 23 to July 12, 1914, inclusive.[2] The street-railway company considers an estimate involving an error of not more than 3.3 per cent as practically exact. If the error is not more than 5 per cent, the estimate is still very good. The average deviation of the forecasts from the average daily traffic was 2,155, or within 3.2 per cent of the correct figure. This error falls well within the limits set by the company. But since averages so often cover up a great many details of importance, certain absolute figures are presented.

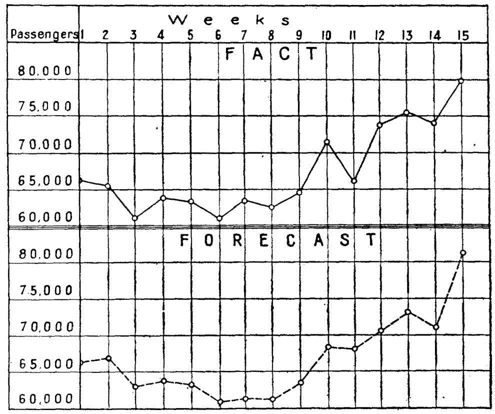

FIG. 4—Diagram showing the agreement between the forecast and the actual figures of street-car traffic in Duluth, Minn., for a period of 15 weeks from March 23 to July 12, 1914.

The smallest error for any given day was 33 on a day when 67,147 passengers were carried, and the largest error was 8,918 when 80,235 passengers were carried. On the latter day a convention of uncertain attendance led to an estimate far too low. The following tabulation gives the percentage of the total number of forecasts for which the error ranged between zero and a specified maximum:

0 to 2500	64%	0 to 4000	82%
0 " 3000	68"	0 " 4500	87"
0 " 3500	80"	0 " 5000	91"

The average daily traffic for the period was 67,548. Using 5 per cent as the maximum error which may enter into the forecast without seriously diminishing its value, the efficiency percentage reaches 79; in other words, in 79 cases out of 100 the error falls under 5 per cent. If an error of 15 per cent in weather forecasts is recognized as permissible, an error admitted by the U. S. Weather Bureau, then the efficiency of the traffic forecasts becomes evident.

The latter half of the forecast period was disturbed by the appearance of the "jitney" after its winter hibernation, by the uncertainty of enforcement of a threatened ordinance regulating it, and by the opening of an extension of the street-railway lines. In spite of these disturbances the average of accuracy was maintained. The influences that produce variations in the traffic returns are many. Yet none seem so powerful as the

[2] This period includes 112 days. The weather map was not available on 12 days, hence no forecast was attempted.

weather. The curves in Figure 4 indicate how well the variations in the forecast agree with the facts.

The investigation was started with a hope merely to demonstrate positively that weather influences passenger traffic to a degree greater than most persons are aware and to make some exact determinations of the character of that influence. It was hardly expected that the results would lead to the ability to forecast traffic. The case is only one of many in the domain of climatology which convince one that the time must come when direct application of the knowledge of the weather influences upon man's daily activities will constitute the normal method of procedure.